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CHANGE IN ENERGY EXPENDITURE AND BRAIN AND ADRENAL CONTENT
OF CATECHOLAMINES IN RATS DURING MUSCULAR LOADING AND HYPOKINESIA

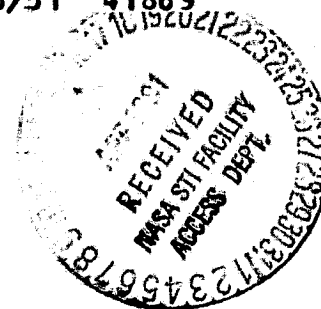
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16. Abstract In male 1-7 mo. old rats, the growth and the protein content of skeletal muscles were higher than in female rats while the O ₂ consumption and the heart rate were lower. This is combined with reduction of the thyroid gland weight and of catecholamine content in adrenals at the age of 7 mos. The development of male and female rats (1-7 mo.) under conditions of systematic muscular loads increases the growth tempo and protein of skeletal muscles and intensifies the degree of reduction of energy expenditure and the heart rate. This is accompanied by the greater reduction of relative weight of the thyroid gland and, at the age of 7 mo., by reduction of the noradrenaline content in the brainstem. Hypodynamic condition have the exact opposite effect.		
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CHANGE IN ENERGY EXPENDITURE AND BRAIN AND ADRENAL CONTENT OF CATE-
CHOLAMINES IN RATS DURING MUSCULAR LOADING AND HYPOKINESIA

By

V. D. Rozanova, T. G. Savkiv and N. A. Khodorova*

Laboratory works have demonstrated that in the process of postnatal onto-
genesis in animals a reduction occurs in the energy expenditures and activity of
the respiratory system and the heart. It is more pronounced the more intensive
the natural motor loads are in the representatives of a certain species of animal
after the occurrence of the posture of standing and locomotion [2-6, 10, 14-17].

Our task was to study the sexual features of growth and development of the
skeletal musculature, degree of reduction in the specific consumption of oxygen
and cardiac activity in rats during their development under conditions of different
forms of physical loads. Until now such type of study was carried out mainly on
males or on animals without their differentiation according to sex. In relation to
the data obtained in previous works on the great pronouncement of the cholinergic
mechanisms of regulation in rats developing under conditions of motor loads [1,
10-13, 15, 16], one of the tasks of this study was to determine the content of
catecholamines (CA) in the brain and adrenal glands in rats developing with a
varying level of muscle activity.

Technique

There were 7 groups of mongrel rats under observation in age from 1 to 7 months;
females and males developing under normal conditions of maintenance (control);

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**Numbers in margin indicate pagination in original foreign text.

females and males developing under physical loads of running; females and males developing under loads of swimming; males developing under conditions of hypokinesia. Running and swimming were conducted every other day, increasing its duration from 5 to 30 min, in age from 1 to 4 months, and from 30 to 100 min. in age from 4 to 7 months with water temperature in the basin equal to 25-26°. Hypokinesia was created by keeping the rats in close cages with temperature 28-32°, corresponding to the thermo-indifferent zone that excluded the thermoregulation load on the skeletal musculature. In age 1, 4, 7 months the body weight and oxygen consumption were determined according to the technique of Kalabukhov-Grad [7] with temperature of 22-23°, i.e., with temperature of the medium for maintaining them in the cages. An exception was the males exposed to hypokinesia for whom the analysis was made at 28-32°. In all the rats the cardiac contraction rate (CCR) was recorded from EKG data. At 4 and 7 months part of the rats were killed (in 2 days after the last load) and the absolute and relative weight of the muscle mass and the concentration of protein in it were determined according to Lowry [19], as well as the content of noradrenaline (N) in the brainstem and the total content of adrenaline (A) and noradrenaline in the adrenal glands by the fluorometric trioxindole method [9]. Due to known data on the effect of thyroid hormones on the level of oxygen consumption the relative weight of the thyroid gland was determined. The results were statistically processed. /305

Study Results

The data of all the experiments are presented in the table. First of all one should focus attention on the difference in the changes of growth and studied functional indices in the control rats depending on sex. Considerable sexual differences are found already in the 4-month age, when sexual maturation is completely finished in the rats. It is shown that the body weight in the control males at 4 and 7 months is 40 and 61% higher than in the females. This difference is mainly reached due to the higher absolute weight of the muscle mass in the first, which is 56 and 50% higher than in the second. The relative weight of the muscle mass in the control males of 4 and 7 months is also higher than in the females. The increased growth of the skeletal musculature in the males is apparently linked to the higher synthesis of protein whose concentration in their muscle tissue is 6 and 4% higher than in the females. Higher rates of growth in the males are

BODY WEIGHT, MUSCLE MASS, PROTEIN CONTENT IN IT, OXYGEN CONSUMPTION (O_2), CARDIAC CONTRACTION RATE (CCR), NORADRENALINE (N) CONTENT IN BRAINSTEM AND SUM OF ADRENALINE (A) AND NORADRENALINE IN ADRENAL GLANDS IN 4 AND 7-MONTH OLD RATS (MALES AND FEMALES), CONTROL AND THOSE DEVELOPING UNDER CONDITIONS OF LOADS OF RUNNING AND SWIMMING OR HYPOKINESIA (M_{-m})

Groups	Age (in months)	Sex	Body weight (g)	Muscle mass weight	Relative muscle mass weight, %	Protein concentration, g %	total, g	O_2 consumption, ml/kg/min	CCR (per min.)	N in brain stem ($\mu\text{g/g}$)	Sum A + N in adrenals ($\mu\text{g/g}$)
Control	1	♂	307 ± 0.8	15.7 ± 0.5	30.2 ± 0.4	20.6 ± 0.6	30 ± 0.1	64.2 ± 0.4	22.0 ± 18.0	0.51 ± 0.02	480.0 ± 9.0
Running	1	♂	349.0 ± 0.0	145.3 ± 4.5	40.2 ± 0.4	22.3 ± 0.2	32.8 ± 1.0	33.2 ± 0.1	365.0 ± 9.1	1.00 ± 0.23	840.0 ± 25.1
Swimming	1	♂	362.7 ± 8.5*	178.3 ± 3.9	45.2 ± 0.3	24.9 ± 0.3	42.3 ± 2.0	25.7 ± 0.1	265.6 ± 8.5	1.06 ± 0.26*	780.0 ± 0.7
Control	4	♂	359.4 ± 9.3*	164.8 ± 3.9	43.7 ± 0.3	24.6 ± 0.4	44.1 ± 1.4	27.2 ± 0.1	274.3 ± 10.5	0.90 ± 0.12*	840.0 ± 0.45*
Running	4	♂	445.0 ± 6.5	186.8 ± 3.4	41.6 ± 0.3	23.0 ± 0.2	40.9 ± 1.4	21.8 ± 0.4	265.8 ± 5.9	0.76 ± 0.03	830.0 ± 17.0
Swimming	4	♂	296.0 ± 8.9	236.7 ± 4.8	46.0 ± 0.7	25.9 ± 0.2	61.0 ± 1.2	17.2 ± 0.1	257.1 ± 5.6	0.51 ± 0.04	788.0 ± 0.9
Control	7	♂	402.5 ± 9.7	210.0 ± 4.6	44.7 ± 0.6	25.1 ± 0.2	54.5 ± 1.1	18.7 ± 0.1	268.5 ± 7.0	0.70 ± 0.16	913.0 ± 0.7
Hypokinesia	7	♂	390.0 ± 6.3	150.4 ± 5.1	40.1 ± 1.0	20.9 ± 0.3	31.5 ± 1.1	32.7 ± 0.9	340.0 ± 8.1	0.86 ± 0.38	830.0 ± 0.9*
Running	7	♂	248.0 ± 5.8	97.3 ± 3.0	38.6 ± 0.3	20.8 ± 0.2	19.9 ± 0.7	38.2 ± 0.1	360.0 ± 5.1	0.90 ± 0.06	730.0 ± 0.59
Swimming	7	♂	264.9 ± 3.2*	119.7 ± 1.4	43.2 ± 0.4	22.7 ± 0.8	28.9 ± 1.0	30.9 ± 0.1	312.9 ± 13.8	0.88 ± 0.10*	738.0 ± 0.04*
Control	4	♀	257.0 ± 3.7*	110.2 ± 1.8	42.9 ± 0.5*	22.4 ± 0.4	22.6 ± 0.7	32.6 ± 0.1	322.9 ± 8.3	0.82 ± 0.05*	750.0 ± 0.04*
Running	4	♀	276.0 ± 4.7	109.4 ± 3.8	39.9 ± 0.6	20.7 ± 0.2	22.9 ± 0.7	29.1 ± 0.4	340.0 ± 0.1	0.83 ± 0.07	970.0 ± 21.0
Swimming	4	♀	318.2 ± 7.6	139.2 ± 4.4	43.2 ± 0.6	22.5 ± 0.2	30.9 ± 0.9	21.3 ± 0.1	285.9 ± 9.9	0.58 ± 0.06	970.0 ± 8.0
Control	7	♀	292.5 ± 7.1	129.3 ± 2.5	43.8 ± 0.6*	22.3 ± 0.1	28.1 ± 1.1	24.5 ± 0.5	365.9 ± 7.7	0.79 ± 0.14	930.0 ± 8.0

Note: The differences between the indices of the control and experimental animals are reliable ($p < 0.05$), except the cases marked by an asterisk (*) where $p > 0.05$.

combined with reduced amounts of energy expenditures and cardiac activity in the state of rest. From 1 to 7 months the oxygen consumption and CCR are reduced in the males by 64.5 and 43.3%, and in the females by 54.7 and 34.8%. Changes in body weight, muscle mass and functional indices in the rats of both sexes in the second half year were less pronounced than in the age 1-7 months (see figure).

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Comparison of the employed parameters in the control males and females in age 4 and 7 months demonstrates that the first are characterized by lower specific amounts of oxygen consumption (by 13 and 24% respectively) as compared to those in the females of 4 and 7 months.

In the control rats by the fourth month the content of noradrenaline in the brainstem and catecholamines in the adrenal glands is increased as compared to the 1-month age. By age 7 months the CA increase continues in the adrenal glands, while in the brainstem the N content is reduced, whereupon this reduction is more pronounced in the males.

Rats of 4 and 7 months (males and females) developing from age 1 month under conditions of systematic motor loads are distinguished by more intensive growth of the skeletal musculature and organism as a whole and reduced energy expenditures and CCR as compared to the indices of the control animals of the same age and sex. Thus, the body weight and muscle mass in the "running" males at 4 and 7 months were 10 and 18%, and the weight of the "swimming" 7 and 10% higher than in the control males. In the experimental females a higher body weight and muscles mass were also found, as well as protein concentration in the muscles as compared to that in the control females. However, this increase is less pronounced than in the males.

The level of energy expenditures and cardiac activity in the state of rest in the experimental rats was lower than in the controls, especially in the males and especially with the running loads. Thus, in the "running" males of 4 and 7 months the specific consumption of oxygen is 24 and 20% lower, and in the swimming rats 15 and 14% lower than in the control males. Correspondingly the CCR in the experimental males of both groups is 12 and 13, and 10 and 10% lower than in the control. In the experimental females from 1 to 7 months the decrease in O_2 consumption and CCR is less pronounced (by 61 and 65%) than in the experimental

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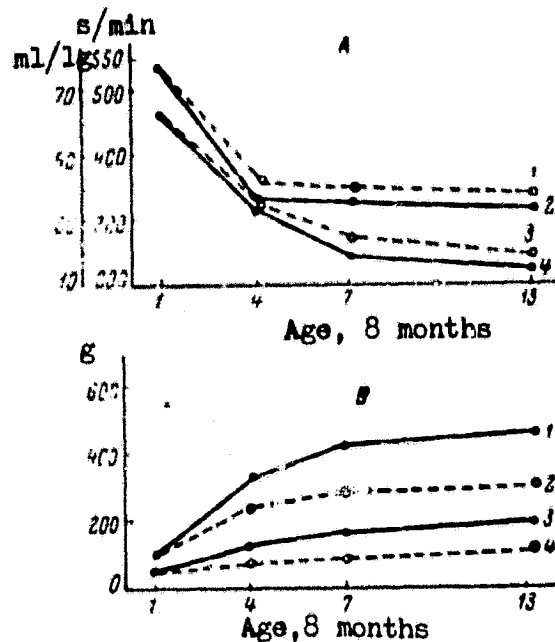


Figure 1. Consumption of Oxygen, Cardiac Contraction Rate (CCR) (A), Body Weight and Weight of Muscle Mass (B) in Rats, Males and Females 1-13 Months
On A: 1--CCR in ♀; 2--CCR in ♂; 3--O₂ consumption in ♀; 4--O₂ consumption in ♂; on B: 1--body weight ♂; 2--body weight ♀; 3--muscle weight ♂; 4--muscle weight ♀.

males (by 74 and 71%).

The table also presents data on the features of the changes in CA in the brain and adrenal glands in experimental rats due to the intensified loads. One can see that at the 4 month age the N content in the brain in them does not differ statistically from the data of the control rats of the same sex and age, although there is a tendency to drop. An exception is the "running" males in whom this trend is lacking, but at the same time a reliable decrease in CA is observed in the adrenal glands. As compared to the 1 month age the N content in the brain stem and the CA in the adrenal glands in the experimental rats of 4 months, as in the control, is increased. Only by 7-month age in the experimental males and females did we establish a reliable decrease in the N in the brain as compared to the amounts in the control, especially with their development under conditions of running loads. Thus, in the 7-month old "running" males the noradrenaline content in the brain stem was 33% lower, and in the "running" females 30% lower than in the control animals of this same age. The decrease in N in the brain stem in the "swimming"

females is less pronounced (by 17%) and in the males is not reliable. The CA content in the adrenals in the experimental rats of age 7 months is not distinguished from the corresponding amounts in the control, with the exception of the "running" males in whom it was reduced.

The cited data make it possible to see that the muscle loads induced non-equivalent changes depending on their nature. The greatest reduction in energy expenditures, cardiac activity and catecholamines is induced by running.

The development of the male rats from 1 to 7 months under conditions of hypokinesia induces a change in the studied indices in the opposite direction. The body weight and muscle mass, as well as the protein concentration in it were 18.9 and 5% (respectively) lower than in the control 7-month old males. On the contrary, the oxygen consumption and CCR were 50 and 15% higher than in the control animals. The CA content in the adrenal glands did not differ from the amount in the control, and the brainstem has a tendency to increase N. The males exposed to hypokinesia for all indices sharply differed from the 7-month olds exposed to hyperkinesia, especially the "running" males.

Discussion of Results

The higher indices of growth and development that we established in the skeletal musculature in the control males as compared to the females, increased amounts of absolute and relative weight of the muscle mass and protein concentration in it were combined with reduced energy expenditures and CCR.

The dependence of the intensity of growth and the degree of reduction in the amounts of oxygen consumption on the level of development of the skeletal musculature to an even greater degree was shown in the experiments where the males and females from 1-month age were placed under conditions of development with systematic loads of running and swimming. The great intensity of growth in the skeletal musculature and organism as a whole (especially under running loads) found here in the males and females can be linked to the increased protein synthesis that is combined in the state of rest with a reduced oxygen consumption and CCR.

It is important to focus attention on the fact that the change in the studied indices in the experimental females brings them closer to those in the control males of the same age.

Above we recalled laboratory works where the importance was shown of the intensification with age in the cholinergic mechanisms of regulation expressed in a reduction in the cholinesterase activity in the blood and in the tissues (in the brain and heart) and economizing the level of energy expenditures and cardiac activity in the state of rest [1, 8, 10-13, 15, 16]. This reduction was found in rats already from age 3 weeks, when the posture of standing develops, and by the age 4 months is sharply pronounced. At the same time the content of CA by this age /308 not only is not reduced, but, on the contrary, is increased. In the experimental rats at age 4 months, in the same way as the control, the N content in the brain and CA in the adrenals is increased as compared to that at age 1 month, reflecting the species peculiarities in the change of monoamines in ontogenesis of rats as compared to other species of animals in whom the N decrease in the brain occurs in earlier periods of ontogenesis [18].

In this respect, in this work we attempted to clarify to what measure the decrease in oxygen consumption and CCR by age 4 months in the control and experimental rats can be linked to the reduction in activity of the thyroid gland. According to our data, the relative weight of the latter in the control males from 1 to 4 months was reduced almost 3-fold (0.0149 ± 0.00136 and $0.00588 \pm 0.00024\%$ respectively) and in the control females almost 2-fold (0.0135 ± 0.00071 and $0.00654 \pm 0.0028\%$). There is an even greater (as compared to the control) reduction in the relative weight of the thyroid gland in the running (up to $0.00500 \pm 0.00010\%$) and in the swimming (up to $0.00511 \pm 0.00011\%$) males from 1 to 4 months of age. In males of 4 months the reduction in relative weight of the thyroid gland as compared to that in the control ($0.00654 \pm 0.00018\%$) is expressed less: with running loads ($0.00609 \pm 0.00012\%$) and in swimming ($0.00615 \pm 0.00014\%$). These data make it possible to hypothesize that the reduction by age 4 months in the O_2 consumption and CCR is linked not only to the increase in the role of the cholinergic mechanisms, but also to the decrease in activity of the thyroid gland.

The oppositely-directed (as compared to the muscle-active males) changes found in the 7-month old males exposed to hypokinesia in the functional indices

linked to the lower development and growth of the skeletal musculature are combined with a higher relative weight of the thyroid gland ($0.00554 \pm 0.00044\%$) than in the control rats ($0.00515 \pm 0.00019\%$), and with the presence of a trend towards increase in the noradrenaline content in the brainstem.

The data obtained in this work confirm the previously found value in our laboratory for the features of development of the skeletal musculature as a factor determining the level of energy expenditures and activity of the autonomic organs, in particular the heart, in different periods of ontogenesis, which was expressed in the energy rule of the skeletal muscles formulated by I. A. Arshavskiy [2-4]. At the same time the importance of the factor of motor activity in the process of growth was unambiguously shown to be dependent on the sex of the developing organism, as well as on the type of motor loads.

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